Solid Rocket Motor Insulation Testing

Dr. Rusty Blanski

AFRL/PRSM

rusty.blanski@edwards.af.mil

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
13 JUL 2005		**-**

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Solid Rocket Motor Insulation Testing	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
Rusty Blanski	**4847**
	5e. TASK NUMBER **0249**
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)	8. PERFORMING ORGANIZATION REPORT NUMBER
Air Force Research Laboratory (AFMC),AFRL/PRSM,10 E. Saturn Blvd.,Edwards AFB,CA,93524-7680	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

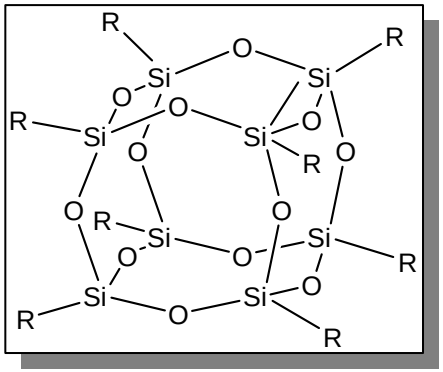
13. SUPPLEMENTARY NOTES

14. ABSTRACT
N/A

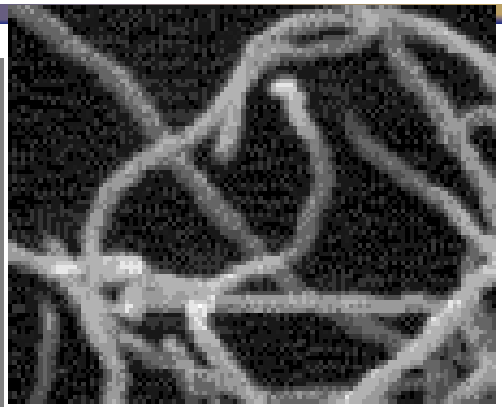
15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**		**15**	

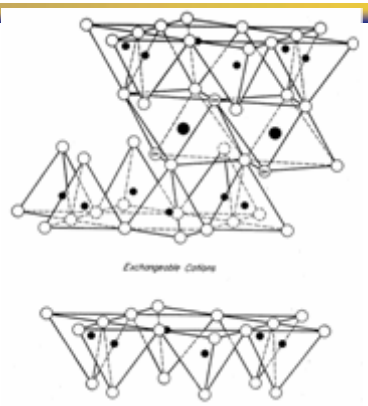
Nanomaterials for Insulation



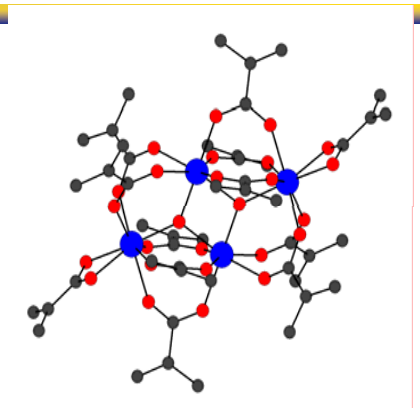
POSS



Carbon Nanofibers



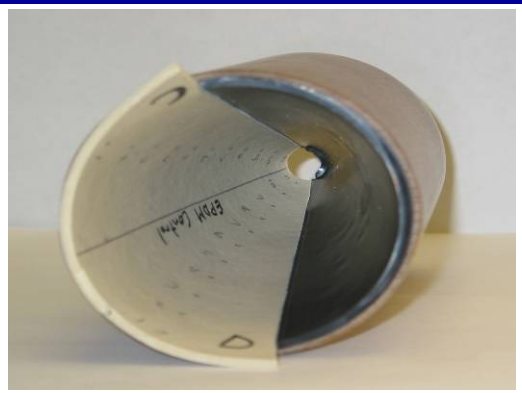
Clays

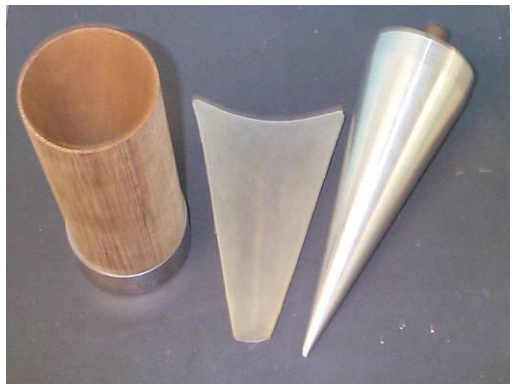


Zr/Hf nanoclusters

Goal: 50% Lower Erosion of Insulation (44% weight reduction, 7.4% booster payload increase)–Phase III IHPRPT (Phase II, 25%)

Objective: Development of Ceramic Forming Polymer and/or Structurally Reinforced Char Layer



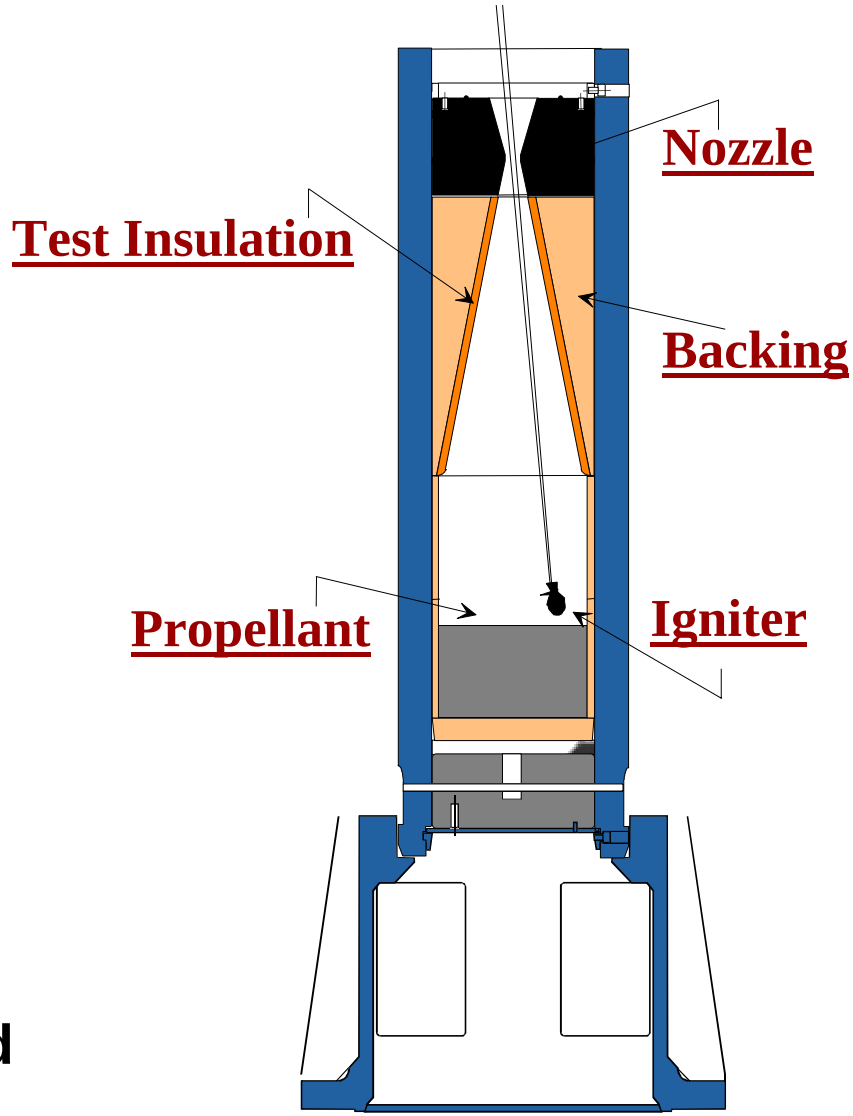


Case Insulation

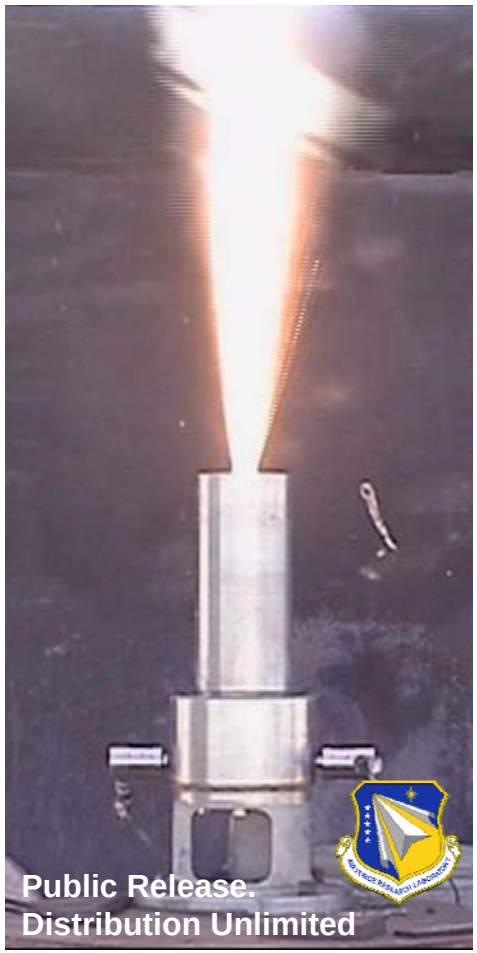
Solid Propellant Insulation Program
In-House Low Cost Screening of New Materials

Present Capabilities:

- **Test facilities developed at AFRL-Edwards (4” Pi-K motor) with various propellants (Shuttle, Titan IV, Sidewinder)**
- **Only 100 g of material needed**
- **Cost (synthesis, part fabrication, ablation test, analysis): $2K**
- **Rapid testing of 5-6 samples per day (or more)**
- **Nozzle materials can also be tested**



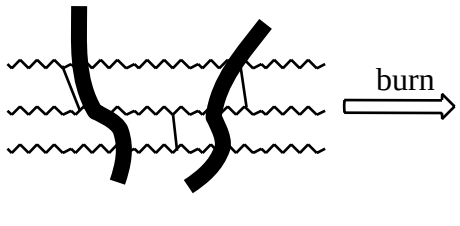
Nanofilled EPDM as Improved Ablative
Potential Pathway to Increase Performance



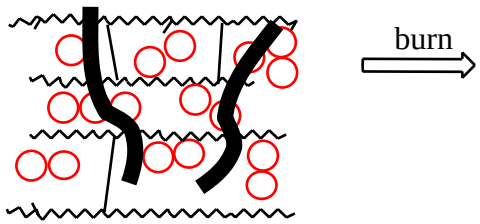
Pi-K Motor Firing

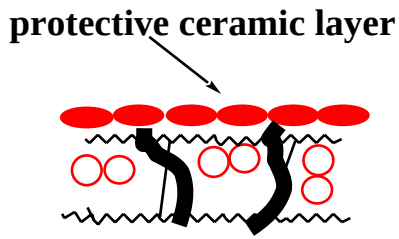
Microfibers

SOTA EPDM Rubber



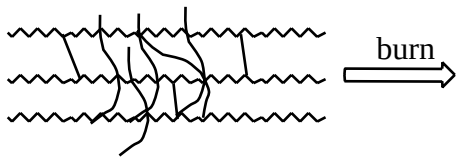
NANO EPDM Rubber



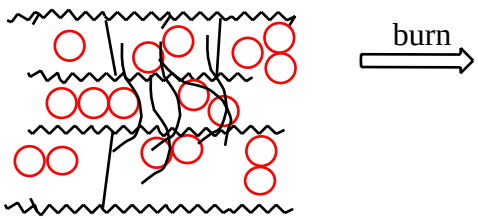


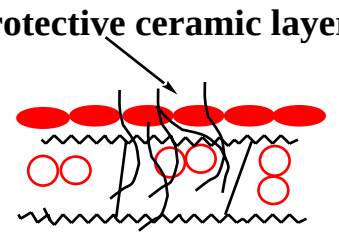
Nanofibers

SOTA EPDM Rubber



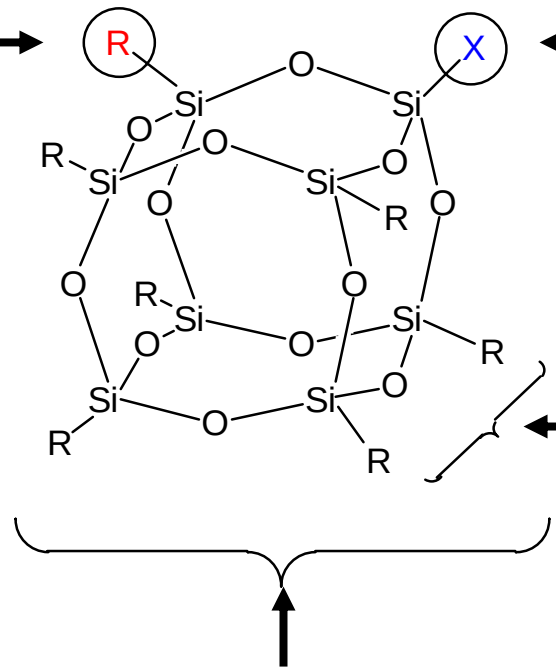
NANO EPDM Rubber





Anatomy of a Polyhedral Oligomeric Silsesquioxane (POSS) Molecule

Nonreactive organic (R) groups for solubilization and compatibilization.



May possess one or more functional groups suitable for polymerization or grafting.

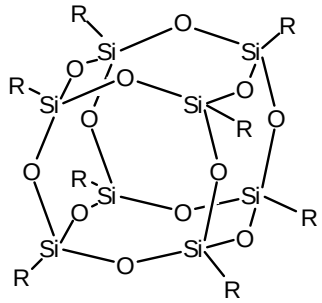
Nanoscopic in size with an Si-Si distance of 0.5 nm and a R-R distance of 1.5 nm.

Thermally and chemically robust hybrid (organic-inorganic) framework.

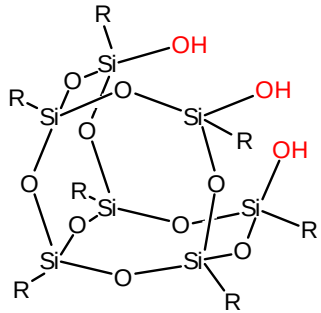
Precise three-dimensional structure for molecular level reinforcement of polymer segments and coils.

The maximization of property enhancements in polymers results from interaction at the nano-level (Edwards AFRL/PRSM ---> POSS monomers)

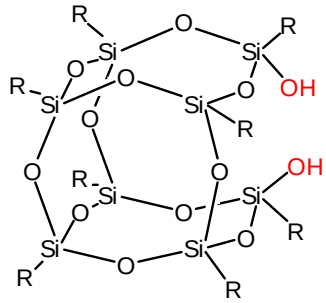
POSS Diversity: An Incredible Assortment of Cage Sizes and R groups



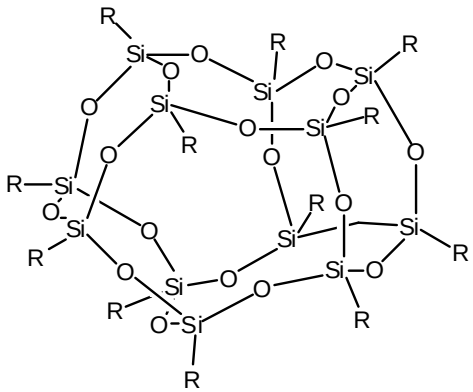
R = **Methyl** **Phenyl**
Isobutyl **Phenethyl**
Cyclopentyl **Octadecyl**
Cyclohexyl **Vinyl**



R = **Isobutyl**
Cyclopentyl
Cyclohexyl
Isooctyl
Ethyl
Phenyl



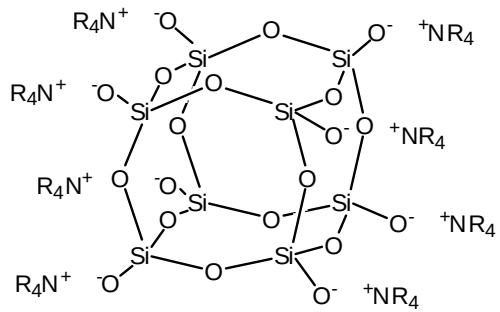
R = **Isobutyl**
Cyclopentyl
Cyclohexyl
Isooctyl



R = **Phenyl**
Trifluoromethylpropyl

Cage Mixtures
(T_8, T_{10}, T_{12})

R = **Vinyl**
Phenethyl
Isooctyl

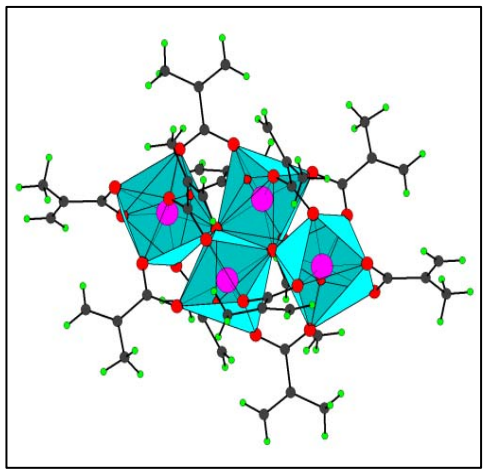


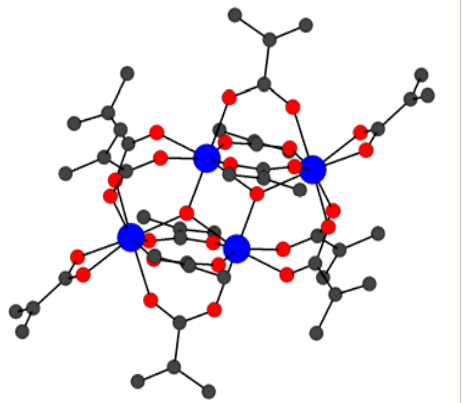
R = **Methyl**

Synthesis of Zirconium Nanoclusters
Prof Ulrich Schubert TU Wien - WOS

In-situ Method

$$4\ Zr(OR)_4 + 14\ R'COOH \longrightarrow Zr_4O_2(OOCR')_{12} + 2\ R'C(O)OR + 14\ ROH$$





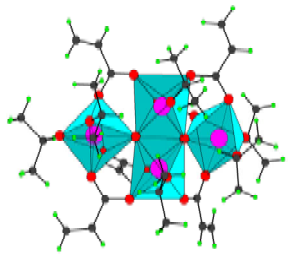
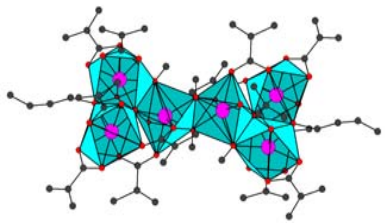
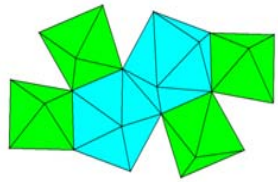
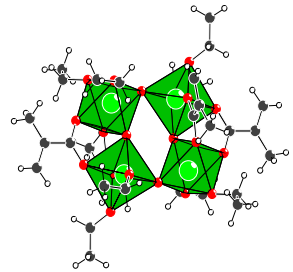
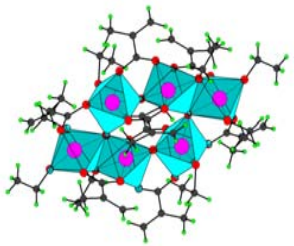
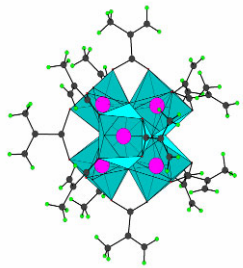
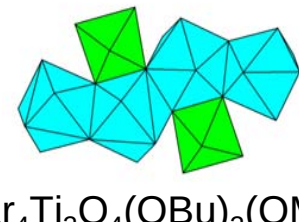
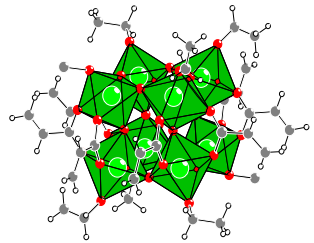
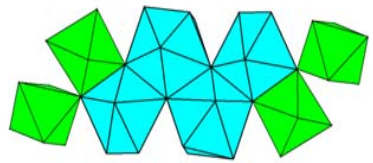
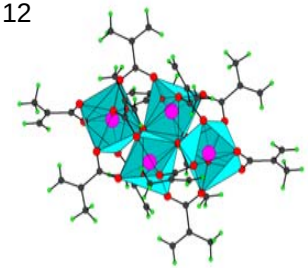
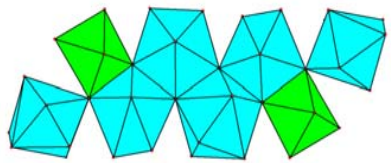
200 grams of Zr nanocluster Delivered to AFRL/PRSM

50 grams of Hf nanocluster also delivered

TU VIENNA Technische Universität Wien — Vienna University of Technology

Wide Variety of Metal Nanoclusters

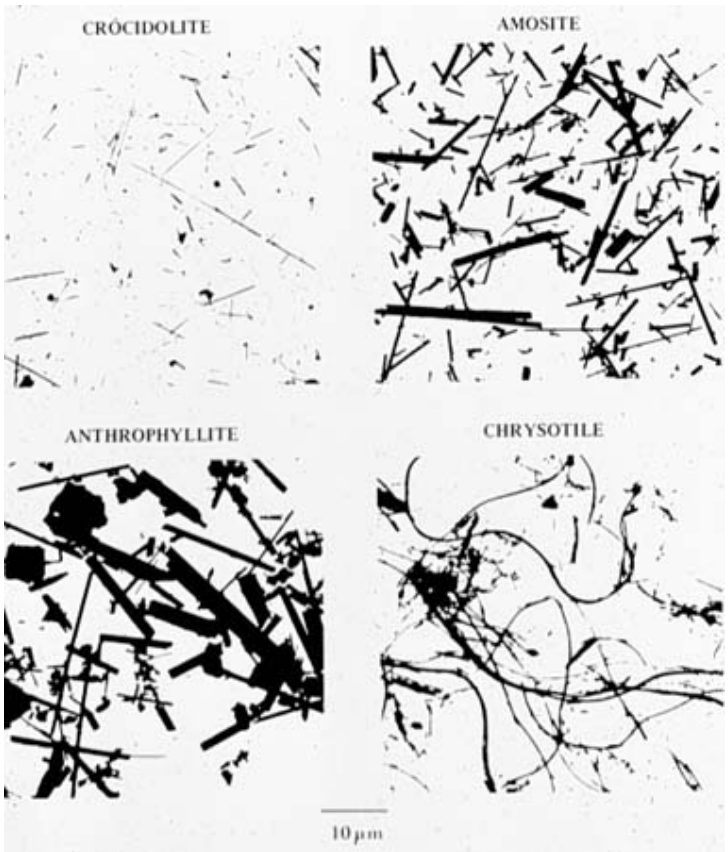
Prof Ulrich Schubert TU Wien - WOS

Ti	Zr or Hf	Mixed Ti / Zr(Hf)	Nb or Ta
 $Ti_4O_2(OPr^i)_6(OMc)_6$	 $Zr_6O_4(OBu)_{10}(OMc)_{10}$	 $Zr_2Ti_4O_4(OBu)_6(OMc)_{10}$	 $M_4O_4(OEt)_8(OMc)_4$ *
 $Ti_6O_4(OEt)_8(OMc)_8$	 $M_6(OH)_4O_4(OMc)_{12}$	 $Zr_4Ti_2O_4(OBu)_2(OMc)_{10}$	 $Ta_8O_{12}(OEt)_8(OAcr)_8$
	 $Zr_4Ti_4O_6(OBu)_4(OMc)_{16}$		
	 $M_4O_2(OMc)_{12}$	 $Zr_6Ti_2O_6(OMc)_{20}$	

* M= Nb: L.Hubert-Pfalzgraf et al.

Other Fibers

- **Asbestos – the first and the best**

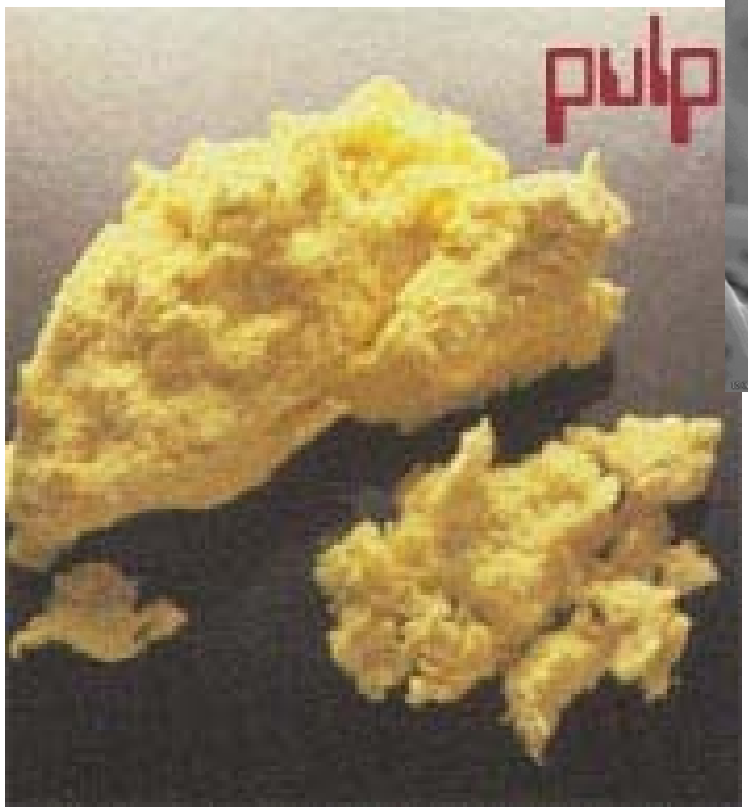


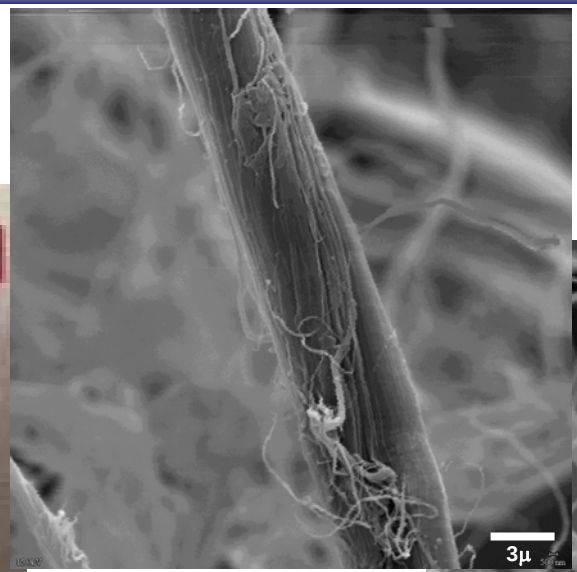
ASBESTOS FIBERS (SCANNING EM) - Amphibole fibers (crocidolite, amosite and anthrophyllite) are rectilinear while the serpentine (chrysotile) fibers are curved, twisted and of different diameters. The serpentine group is more prevalently used in industry however the amphiboles are more pathogenic in regards to induction of malignant mesotheliomas.

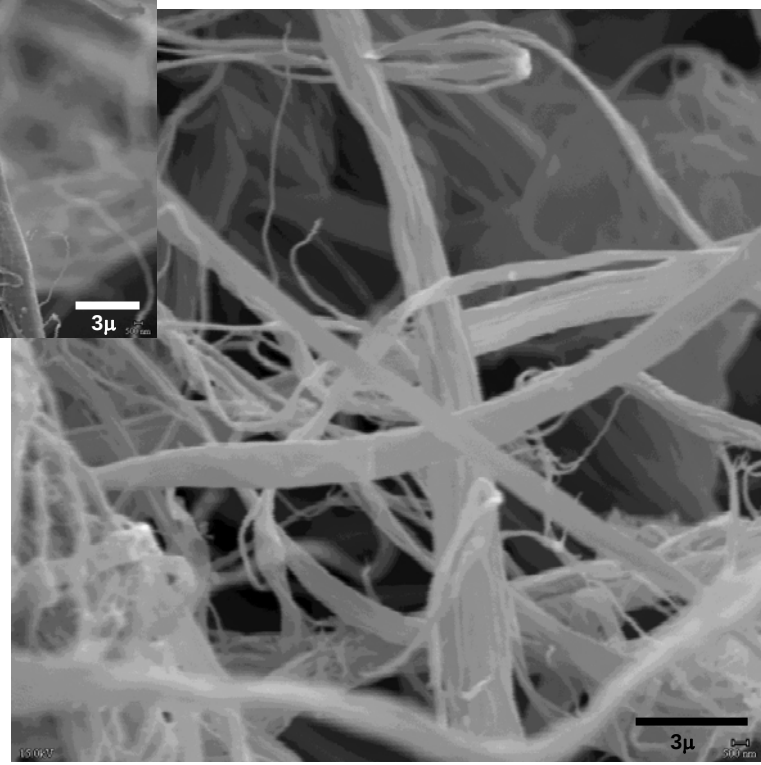
Source: Tulane

The most commonly used fiber is the Chrysotile fiber (pliable and nonfriable)

Other Fibers
Kevlar Fibers







Kevlar Pulp

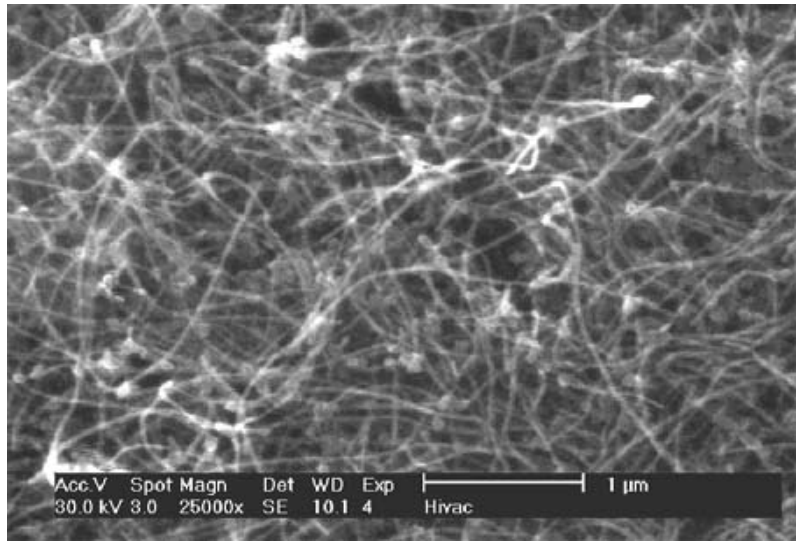
Bulk Phase, 1/4” long

Kevlar Fibers

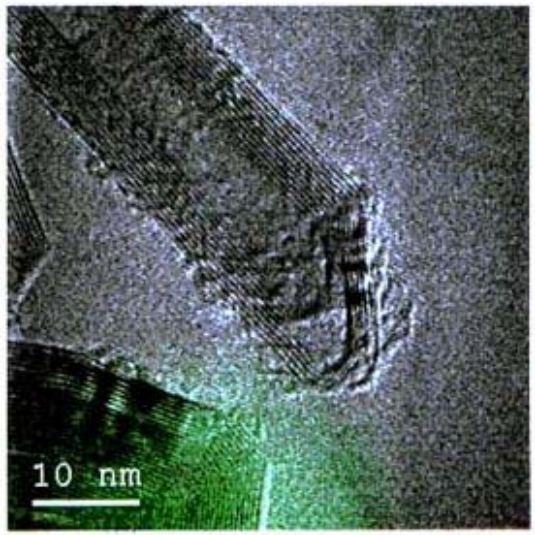
SEM

Carbon Nanofibers

- **Many Types**
  - **Single Wall Nanotubes**
    - **1.2-1.4 nm diameter**
    - **2-5 μ long**
    - **$370K/Kg as grown**
    - **$950K/Kg purified**
  - **Multiwall Nanotubes**
    - **2-20 nm diameter**
    - **100 nm to ~ 5 μ long**
    - **5-20 graphitic layers**
    - **$110K/Kg as grown**
    - **$170K/Kg purified**



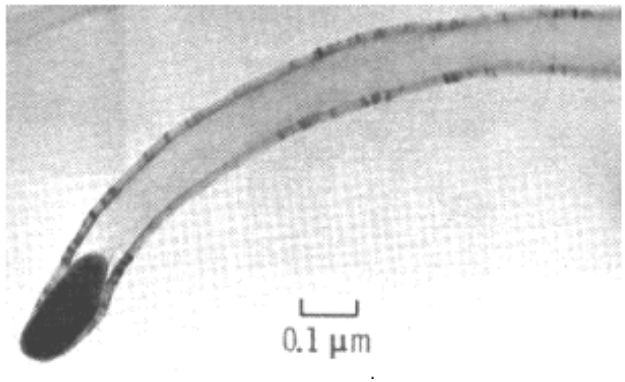
SWNT SEM from SES Research

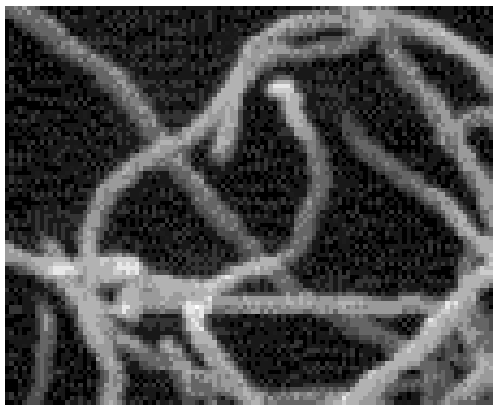


MWNT by STM

Vapor Grown Carbon Fiber

- **ASI Price: < $90/pound**
- **Thermally Stable**
- **Small size lends well for intimate mixing**
- **Shear considerations**
- **Grades Available: PR-19, PR-24 etc.**
- **Many surface treatments available**



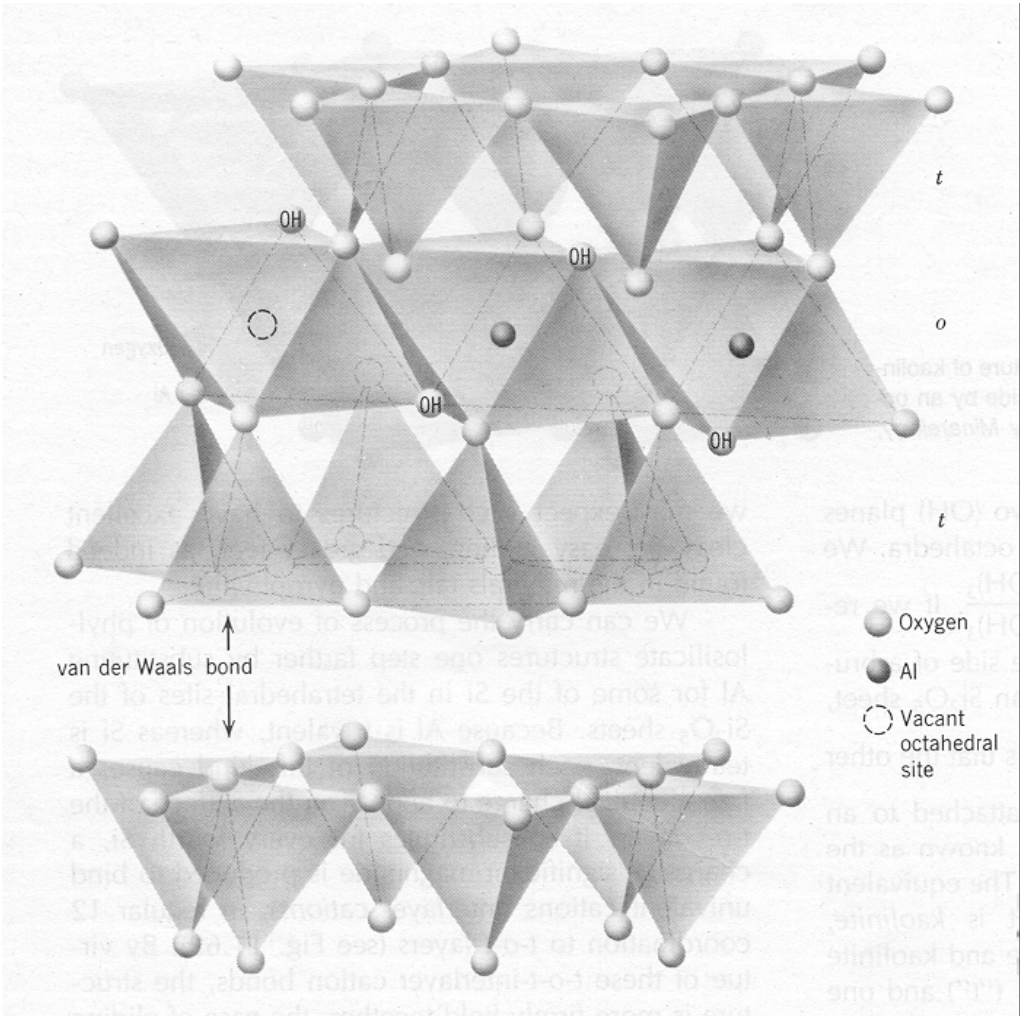


Carbon Nanofibers
Source: ASI

	PR-1	PR-11	PR-19	PR-24
Production	Lab scale	Bench scale	Full scale	Full scale
Diameter, nanometers	100 to 200	100 to 200	100 to 200	60 to 150
Length, nanometers	30,000 to 100,000	30,000 to 100,000	30,000 to 100,000	30,000 to 100,000
Comments	As grown material contains CVD carbon	As grown material contains CVD carbon	As grown material contains CVD carbon	As grown material essentially free of CVD carbon

AG, as grown fiber. PS, cleaned fiber. LHT, graphitized fiber. HHT, iron free graphitized fiber.

Modified Clays



- **Organically Modified (generally with quaternary ammonium or phosphonium salts) to increase dispersion**
- **Previous results show promise for SRM insulation (Vaia, Lichtenhan 1997)**

Montmorillonite nanoclay

Potential Transition Opportunities
Less Insulation Means More Propellant

Source: Aerojet

Atlas V test firing at Edwards (AFRL) AFB
May 2005

In-House SRM Insulation Testing
Acknowledgements

- Mr. Hieu Nguyen (Firing Engineer; Sample Analysis)
- Dr. Tom Hawkins and Del Jung (Motor Firings)
- Mr. Phil Counts (PRSM Master Machinist)
- Mr. Pat Ruth (Sample Preparation, measurement)
- Prof Joe Koo
- Prof Ulrich Schubert
- AFRL/PRS and AFOSR ($$$)